23-2-89

~~SECRET~~

Central Intelligence Agency

Washington, D.C. 20505

CIA SW 91-20014 M

DIRECTORATE OF INTELLIGENCE

5 April 1991

Assessment of Soviet Space Transportation Technology

Summary

The primary strength of the Soviet space program is its space transportation systems. While much of their success is dependent on their conservative use of technology, there are areas where they are world leaders, such as in storable liquid-propellant engine technology. In addition, the Soviets have a strong research program investigating a wide variety of new technologies for incorporation into future transportation systems. Soviet progress in developing space transportation systems is likely to slow as the deteriorating Soviet economy causes cuts in space funding. As a result of the deteriorating economic climate in the Soviet Union, there is enormous incentive for the Soviets to sell existing systems to the West and seek Western partners for jointly developing future systems.

.....

This memorandum was prepared by , the Office of Scientific and Weapons Research. Comments and queries are welcome and may be directed to OSWR

SW M 20014

CL BY
DECL OADR
DRV FM

Introduction

Space transportation technology can be broadly categorized into seven components:

- Propulsion systems.
- Aerothermodynamics.[1]
- Structures and materials.
- Environmental control and life support systems.
- Navigation and guidance.
- Systems engineering and integration.
- Launch support and operations.

Soviet capabilities in these areas range from being the world leaders in storable liquid propulsion technology to having very limited capabilities in some areas of aerothermodynamics due to their lack of high-speed computers. While the Soviets are very conservative in incorporating new technologies in designing and building their systems, they have relatively advanced programs for researching and developing advanced technologies for future systems.

Propulsion Systems

Liquid-Propellant Rocket Technology

The Soviets are the world leaders in storable liquid-propellant rocket technology, based on the design of their space launchers and ICBMs, using closed-loop cycle storable liquid-propellant engines. The Soviet lead in storable-propellant technology applications over the US is about 10 years. The Soviets, however, were late in flying a liquid oxygen/liquid hydrogen propelled vehicle, having had several significant test failures in the late 1960s. They reached this goal in 1987 when the SL-17 (Energiya) heavy lift launch vehicle flew for the first time.

Since the early 1960s, the Soviets have conducted extensive research and testing programs in high-energy liquid propellants and engine technology. The State Institute of Applied Chemistry (GIPKh) at Leningrad is the key Soviet chemical industry organization for liquid missile propellant research. In a 1981 text, V. P. Glushko, one of the top Soviet rocket engine

---

[1] Aerothermodynamics characterizes the fluid dynamic and thermodynamic phenomena that govern the flight of aerospace vehicles as they exit, enter, and maneuver in an atmosphere. In that it characterizes a vehicle's interaction with the environment, it impacts all areas of a vehicle including its flight control, structures, materials, aerodynamic performance, flight/ground operations, and propulsion.

designers, stated that an experimental closed-loop (staged combustion) engine, which used fluorine and ammonia, was built and tested. The Soviets have mentioned the use of slush Hydrogen in their literature, but there has been no direct evidence to indicate any development

[ ], they had a tripropellant (fluorine/lithium-hydrogen) engine in an advanced stage of research. Soviet texts continue to mention tripropellants, but there has been no other evidence of work on this or any other metallized cryogenic propellant.

Nuclear Rocket Technology

The Soviet Union is investigating several approaches to nuclear rocket propulsion systems. These include solid core reactors using hydrogen propellants, gas and plasma core reactors, and aerosol or levitated bed reactors. We believe primary focus is on solid core reactor technology, with gas core reactor development receiving considerable attention and other systems a distant third.

Soviet programs in nuclear reactor propulsion are highly classified and involve a large number of institutions. There appears to be close cooperation among a number of institutions involved. Reactor technology is investigated at the Kurchatov Institute of Atomic Energy, at the Scientific Research Institute of Thermal Processes, at the Central Design Bureau of Experimental Machine Building in Kaliningrad, and the Turayevo branch of the Favorskiy Design Bureau. A number of other institutes study materials and thermodynamic properties, and systems integration and control.

Hypersonic Research

The Soviets are actively researching hypersonic flight technologies directly applicable to trans-atmospheric vehicles or flyback first stages for space launch systems. Soviet research indicates that they have the necessary technology to design external compression inlets operation up to Mach 3. By 1982 the technology was available to begin development of an uncooled inlet for a scramjet operating up to Mach 6 for short (under two minutes) flight times. The technology for a first-generation cooled inlet could have been available in 1986. The technology necessary to design a completely cooled inlet capable of steady-state operation up to Mach 8 will not be available until the early 1990 . Potential applications are a hypersonic cruising vehicle capable of flight speeds approaching Mach 7 at high altitude or an air-breathing space launch system capable of acceleration through Mach 8

The structural technology required to use cryogenics as a coolant was developed by the Soviet liquid rocket industry during the early 1960s. Extending this knowledge to hydrogen or methane fuel being used to cool an engine and critical vehicle components would require advanced research and will not be available to the Soviets until the early 1990s.

Aerothermodynamics

Soviet lack of high-speed computers puts them at a considerable disadvantage for mathematical modeling. While the Soviets have access to all the major Western computational fluid dynamic codes, their computers are too slow and have memories too small to do precision simulation work. The Soviets used CFD modeling for design of the Buran, but it took a subordinate role to flight testing of models. The Soviets flew both orbital and suborbital subscale flight test vehicles (designated Bor-4 and Bor-5) in designing their shuttle and used these results to confirm/verify their rudimentary computer modeling. The Soviets also built full scale models of the Buran for drop testing and equipped one version with jet engines for aerodynamic testing.

Structures and Materials

Fabrication/Manufacturing

Soviet and Western technologies in metals and alloys are generally comparable, but the Soviets lag in several key areas of fabrication and production. The Soviets meet their structural requirements in fielding effective systems through innovative engineering. The Soviets have an adequate capability to fabricate advanced composite materials into structural components for aerospace uses. Rather sophisticated structures have been built, largely with manual fabrication and inspection techniques.

Metallic Materials

The Soviets can be credited with possessing an excellent capability in many areas of metallic materials to include titanium, electroslag technology, thermomechanical treatments, aluminum-lithium alloys, and powder metallurgy. In current propulsion systems the Soviets rely almost exclusively on metallic materials.

The Soviets include a variety of advanced materials in their propulsion systems. The RD-170 engine has a turbo-pump shaft made of titanium, produced by powder metallurgical techniques.

The cryogenic hydrogen tank for the SL-17 is claimed to be fabricated from machined aluminum-lithium alloy.

Composites

The Buran is the only Soviet space system that makes extensive use of composites. The protective tiles on Buran are made of superfine quartz fibers with flexible high-temperature organic fibers. A graphite material is used on the areas subjected to greatest reentry heating, reported to be as high as 1,600 degrees Centigrade. The doors for the Buran,

The wing and tail leading edges of Buran are fabricated from two-directional carbon-carbon composites. The carbon-carbon leading edges are coated with molybdenum disilicide for protection from oxidation. Metal matrix composite tubing is used extensively throughout the fuselage, and carbon/polyimide composites are used in the structure near the engines.

The plasmatron is a plasma induction furnace that provides a pure, uncontaminated environment for testing items ranging from 2-20 cm in diameter. The facility can simulate many combinations of reentry conditions by varying the temperature and pressure.

Environmental Control and Life Support Systems

The environmental control and life support systems found on the Soviet space station Mir are representative of Soviet capabilities in this area. With only a few exceptions Mir's environment and life support systems show a relatively low level of technological sophistication and are strictly functional in nature. System failures due to the inadequacies of Soviet technology are expected and are taken into account during design to ensure the safety of the cosmonauts. Soviet engineers are well aware of the limitations of Soviet technology and seldom, if ever, design systems that are dependent on state-of-the-art technology. Soviet success in space has come from incrementally upgrading their spacecraft with well proven off-the-shelf technologies.

The Soviets recognize the benefit of a closed life support system and are developing technologies to achieve this end. While Mir contains systems for producing oxygen and water from cosmonaut waste products, they are still largely dependent on Progress resupply craft for replenishing consumables. Mir continues the long-standing Soviet practice of maintaining an

interior shirt-sleeve environment of approximately sea level pressure and the nitrogen/oxygen composition of air (20% oxygen). The Soviets have a redundant system with oxygen being generated by the electrolysis water, or released from cartridges brought on Progress

The Soviets maintain an atmospheric composition (by volume) of:

Nitrogen	78% max
Oxygen	21 to 40%
Carbon Dioxide	3% max
Helium	0.1% max
Hydrogen	2% max

The temperature on Mir is maintained between 18 and 28 degrees Celsius. The somewhat high upper limit of 28 degrees was provided to insure comfort in the station when the cosmonauts are exposed to direct draft (from circulation fans). The cosmonauts often complain about the temperature being too high, particularly during exercise. According to the Soviets the thermal regulating system uses "heat pipes", located on the outside of the station, to regulate the temperature. The station pressure is maintained between 634 and 970 mm Hg and relative humidity between 30 and 70%.

The primary source of water is that delivered by Progress vehicles. It is stored in 10 liter tanks and can remain potable for a year. Each cosmonaut is rationed 2 liters of water per day. Some water regeneration is performed on condensate water, as had been done on Salyut stations, but the Soviets have had difficulty in keeping the system working and the cosmonauts are reluctant to drink recycled water

The Soviet condensate water purification system consists of successive columns with ion exchange resins (cation exchange, anion exchange, mixed layer, and activated carbon). The necessary degree of water purification is reached by manipulating the column working volumes, grain diameter, optimal proportions of ammonite and cationite, and quantity of activated charcoal. The Soviets claim this purification system is durable and reliable.

Navigation and Guidance

Soviet launch vehicles employ a wide variation in navigation techniques. The navigational coordinate systems appear to be different on different vehicles. On some vehicles, the navigational accelerometers appear to be body mounted, while on others they are mounted on inertially fixed or torqued platform

systems. Also, the number of accelerometers used and the platform accelerometer mounting axes differ between vehicles.

Guidance on Soviet vehicles is believed to involve generating errors based on comparing programmed attitude and velocity histories (computed and stored in the vehicle prior to launch) with the actual values attained during flight. This guidance scheme is implemented successfully by the Soviets, primarily because they have developed engines with thrust magnitude control. Vehicles with the ability to vary thrust magnitude, as well as direction, can control the vehicle velocity vector to an arbitrary degree during the flight, depending only on the response time and limits of the control and sensor systems. Guidance computations are greatly simplified compared to vehicles without thrust magnitude control

Sensing vehicle attitude deviations from the reference attitude is accomplished on all vehicles by using a three-axis gyrostabilized platform. (Depending on application, the platform is either inertially referenced or torqued in the pitch plane.) The vehicle attitude deviations are probably determined from each of three (pitch, yaw, roll) gimbal angle pick-offs. These attitude deviations are then used in the computation function to drive attitude errors.

Systems Engineering and Integration

The Soviets use a schedule-dominated management approach for system development. Technology selection occurs early in a schedule-dominant management style--before the full-scale engineering phase. This management approach, similar to that used by US corporations for the development of large commercial systems, is one in which meeting a predetermined delivery date takes precedence over changing the system's design during development. Technology development for a new Soviet system typically takes 12 to 15 years, and actual system development averages another 12 to 15 years, times which have not changed since the late 1950s.

The development time for a Soviet system is not reduced by implementing what the United States would consider a "crash" program. When the Soviets describe a program as "accelerated", their aim is to hold to the normal schedule even when a project is difficult or complex. When a Soviet program is described as "priority", that should be interpreted to mean that it is allowed first call on resources rather than to speed up the program. The Soviets have used their conservative approach in selecting technology since the late 1960s. They wait until a technology has proved to be producible before beginning full-scale system development. The Soviets tried some programs in the late 1950s

and early 1960s where they selected unproven technologies and had major failures, [ ].

The following is a description of the design phases for an SLV [ ],

Technical Proposals (8-9 months)

- Study of the technical demands.
- Comparison of choices for design parameters, type of engines, launch pads, etc.

Sketch Project (1 year)

- Calculations of aerodynamics, reliability.
- Cost calculation for prototype.
- Preliminary project plan.

Technical Project

- Documentation for preliminary production.
- Mockups and system prototype production.
- Overall plan for project.

Flight Testing
Serial Production

Launch Support and Operations

There are two major facilities for the launching of milita and civilian spacecraft into orbit. Tyuratam and Plesetsk are located in remote areas of the USSR primarily for safety and security reasons. Facilities for the receipt, assembly, checkout, transport, launch, and tracking of missiles and space boosters are located at each of the test centers. In addition, support facilities are present at these centers which are used for payload processing, propellant handling, administration/personnel housing, utilities, and construction support.

Approximately 60 percent of Soviet launches each year take place from Plesetsk. These are primarily military reconnaissan systems that are being launched into high inclinations. Tyurat is the southernmost Soviet launch facility and is used for military, civil, scientific launches, and all manned launches. Plesetsk has pads for launching the SL-4, -6, -8, -14, and -16, while Tyuratam has pads for the SL-4, -6, -11, -12/13, -16, and -17. Each facility has multiple pads for each vehicle that is launched from it.

All Soviet launch systems, regardless of physical size, are assembled, and have their initial checkout accomplished horizontally under one roof. Payload mating is normally conducted at the launch system preparation facility, and the complete system is transported horizontally to the launch pad by rail. This practice minimizes the on-pad time, allowing fast pad turnaround time and minimal system exposure to inclement weather and intelligence collection efforts. This practice also permits rapid removal of the vehicle from the launch pad in the event of a system malfunction.

Outlook

The collapsing Soviet economy will significantly slow development of new space transportation vehicles in the Soviet Union. The Soviet space program is no longer operating in an environment of steadily increasing budgets. According to press reports, space funding for 1989 and 1990 was cut by 10-20 percent. The existing excess of launch vehicles in the Soviet Union will make programs for developing new ones particularly vulnerable to cuts. Soviet space transportation technology is likely to suffer as money is shifted away from development of new transportation systems to meeting an increased call for directing space resources toward solving civil needs. There is already a scramble among Soviet space industries to find alternate financing, either through sales to the West or programs for joint research and development with Western organizations.

The Soviets already have a significant excess launch capacity. Over the past two years the Soviet yearly launch rate has decreased from 90-100 per year through the 1980s, to 75 per year, leaving them with an excess production capacity. The newest Soviet systems, the SL-17 Energiya and the Buran shuttle, currently have no payloads to be launched on them. Delays or curtailments in future programs, such as the Mir II space station, will diminish the need for new transportation systems to support or launch them.

Most Soviet space industries are looking for sales of space technology to the West to makeup for their budget shortfalls. The historically secretive Soviet space program now more resembles a garage sale. The Soviets have placed a for sale sign on almost everything connected with their space program, from launch vehicles, to individual rocket engines, to proposals for jointly developing and manufacturing a reusable space plane launched from the top of the Soviet AN-225. While they have been unsuccessful so far, the Soviets will likely continue their efforts to work with the West. Almost all of the Soviet commercial offerings are derived from military systems whose development costs are alreadv defrayed and thereby pose little additional financial risk.

SUBJECT: Assessment of Soviet Space Transportation Technology

EXTERNAL DISTRIBUTION:

~~SECRET~~

SUBJECT: Assessment of Soviet Space Transportation Technology